

**THE EXTINCTION PROCESS FOR VENUSIAN DOMICAL SHIELD VOLCANOES.** R. R. Herrick<sup>1</sup> and C. A. Marsh<sup>2</sup>, <sup>1</sup>Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston, TX 77058, herrick@lpi6.jsc.nasa.gov, <sup>2</sup>Dept. Geological Sciences, University of Texas, Austin, TX 78712.

A regional study was conducted of Kunhild (19N, 80E) and Ereshkigal (21N, 85E), two large volcanoes that superficially resemble previously studied Sif Mons [1,2] and Sappho Patera [2,3], respectively. However, the Kunhild-Ereshkigal region has a negligible geoid signature and may be a sight of extinct mantle upwelling. Kunhild, unlike Sif, has a late-forming depressed central region ~200 km across and 600 m deep. We have identified 29 large volcanoes that are Sif-like in superficial appearance. Twelve have a large central depression and appear to be isostatically compensated, while most without a depression have positive isostatic anomalies. We suggest that the death of a domical Venusian shield volcano often involves sagging of the center, perhaps due to removal of a central thermal anomaly at depth.

**KUNHILD AND ERESHKIGAL.** Kunhild and Ereshkigal are two adjacent volcanoes north of Ovda Regio with flow margins 700-800 km in diameter and elevations ~1.5 km above surrounding terrain. Their radar appearance is similar to previously studied regions of clustered large volcanoes interpreted to be currently or recently active and located over ongoing mantle upwelling [1,2,3,4]. Unlike those regions Kunhild and Ereshkigal are not located over a broad geoid high and have free-air anomalies of ~20 mGals. Kunhild & Ereshkigal have negligible isostatic anomalies and are consistent with Airy compensation at the base of an assumed 30-km thick crust. In contrast, Sif Mons has a 50 mGal isostatic anomaly with the same assumed crustal thickness.

We constructed a general geologic history using radar imagery and altimetry supplemented with stereo topography. Fig. 1 shows the region with the gross morphological units outlined. The oldest units in the region are several heavily deformed areas (DZ) that include contractional folding to the NW and SW of Kunhild and an upraised extensional rift S of Kunhild. A series of plains deposits (FP) embayed all but the high-standing topography. Fracturing and folding continued including formation of long, (> 1000 km) thin extensional N-S striking fractures throughout the eastern half of FP. Two younger units occur that are of unknown stratigraphic relationship to the volcanoes: a plains unit to the NW (EP) and a large shield field to the SE (SF).

Ereshkigal appears to have formed earlier than Kunhild. There appears to have been two major flow episodes for Ereshkigal (E1 and later E2) with an intermediate episode of collapse of the central region. The collapsed region is roughly 200 x 300 km and presently ~700 m deep. The flows of E2 are basically

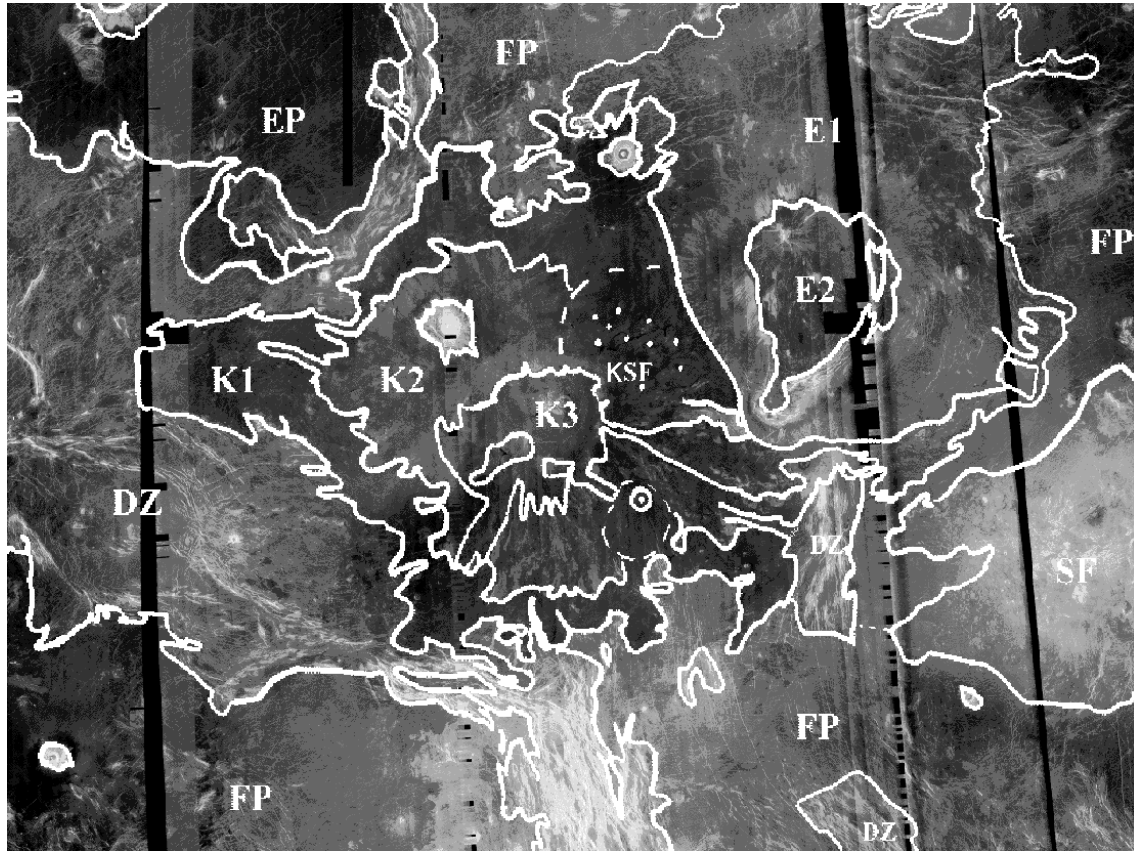
contained within the walls of the collapsed region.

The visible flows of Kunhild postdate all other volcanic activity in the region, although it is possible that Kunhild and Ereshkigal began forming before or coincident with units they now bury. Three major flow units are associated with Kunhild (K1, K2, K3 in order of decreasing age). The eastern flows of these units are largely consistent with the existing topography of Ereshkigal, indicating that most of the tectonic deformation of Ereshkigal predates the surface flow units of Kunhild. However, post-Kunhild tilting and extension of Ereshkigal is indicated by stereo topography of the SW Ereshkigal-Kunhild boundary and the presence of fractures that emanate from Ereshkigal and cross K3. Collapse of the central area of Kunhild predates deposition of K3 and the subsequent shield field (KSF).

While Kunhild's flows are the last volcanic activity in the area, some wrinkle ridge formation and a couple of craters appear to postdate Kunhild. In summary, Kunhild largely postdates Ereshkigal, both volcanoes are presently extinct, and both volcanoes underwent a central sagging late in their evolution. Ereshkigal's sagging appears similar to Sappho Patera's [3] and is wide enough to be considered almost corona-like.

**OTHER DOMICAL VOLCANOES.** Our analysis of Kunhild led us to pose the hypothesis that a Sif-like volcano will sag in the center like Kunhild when it becomes extinct. Using radar imagery we identified 29 large volcanoes that we classify as domical shield volcanoes. These volcanoes are radially symmetric, do not have through-going rifts (although they may bury existing rifts) or sharp summit peaks, and do not have obvious corona-like features. Some familiar examples illustrate our classification: Bell Regio volcanoes - all domical, Atla - all not domical, Sappho and Ereshkigal - not domical.

To test our hypothesis we looked at the topography of these 29 volcanoes to determine if any other than Kunhild have a depressed central region. Twelve of these volcanoes have these depressed regions similar to Kunhild's while two have a resurgent dome. We then calculated the isostatic anomaly for each volcano assuming a 30-km nominal crustal thickness (Fig. 2). All of the volcanoes with the sag feature have low isostatic anomalies while most, but not all, with a domical topographic profile have significant positive anomalies. In other words volcanoes with the sag feature are consistent with isostatic support (and extinction) while most without sagging appear dynamically supported (and active).

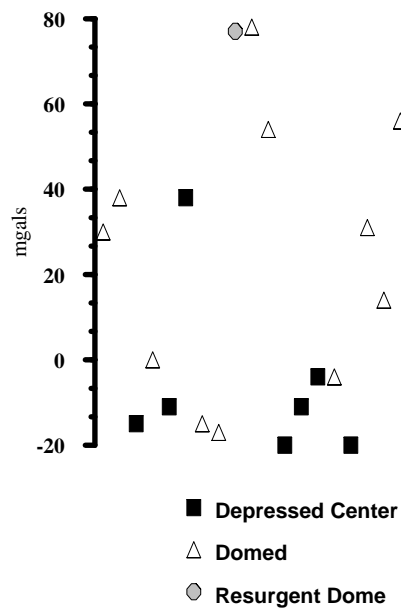


**Fig. 1** Kunhild and Ereshkigal with major morphologic units overlaid. Image is 1800 x 1350 km and centered on 12.6N, 80.5.

Post-volcano regional wrinkle ridge formation is common among the volcanoes with sag features and supports the idea that these volcanoes are extinct.

**A RELATION TO CORONAE?** If the inward sagging of Kunhild and similar features is caldera collapse caused by magma withdrawal, then this is a fundamentally different process from coronae formation. However, the sagging could be associated with removal of a thermal anomaly beneath a hot spot. If so, a spectrum of features from Kunhild-like to Ereshkigal-like to true coronae may exist in the several-hundred-km diameter size range. We suggest that variation in the size and duration of the tail associated with the initial mantle thermal diapir may cause this spectrum. Detached diapirs with no tail form coronae while diapirs with tails connected to the core-mantle boundary have long-lived volcanism that constructs large shield volcanoes. Such a scenario is possible if mantle convection is in the hard turbulence regime.

**REFERENCES.** [1] Senske et al. (1992) *JGR*, 97, 13395. [2] Grimm R.E. and Phillips R.J. (1992) *JGR*, 97, 16035. [3] McGill G.E. (1994) *JGR*, 99, 23149. [4] Campbell B.A. and Rogers P.G. (1994) *JGR*, 99, 21153.



**Fig. 2.** Isostatic gravity anomalies for 29 domical shield volcanoes. Values at or below zero indicate features consistent with Airy compensation.